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BEHAVIOUR OF STRUCTURAL INSULATED PANELS (SIPS) UNDER BOTH SHORT-TERM AND LONG-TERM LOADINGS

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Abstract: Structural Insulated Panels (SIPs), as a load-bearing construction material, have recently attracted continually growing interest. They are structurally sufficient, energy efficient, easy to use in construction and more sustainable. SIPs are a composite sandwich panel system, typically made of two oriented strand board (OSB) panels and one insulation core material such as expanded polystyrene (EPS) or polyurethane (PUR). They have high strength-to-weight ratio and can resist axial, transverse and racking loads. Therefore, they can be used as structural materials for roof, wall and floor panels. An entire building structure can be made of SIPs without including many conventional construction materials such as steel or masonry. Due to the limited application and research on SIPs, the knowledge of this material is still lacking. This is exacerbated by the fact that the structural performance of SIPs has been reported varies from manufacturer to manufacturer as they use different SIP construction and connection details. In applying SIPs as structural materials, apart from addressing conventional structural issues, there is another major concern related to their long-term performance, mainly caused by creep. Both facial and core materials experience high creep behaviour, and it has been found that the creep of SIPs is predominantly caused by the core material. This paper will report studies conducted at University of Birmingham on structural behaviours of SIPs under both short-term and long-term loadings.

Keywords: *Structural insulated panels; SIPs; Panel-to-panel connections; Structural behaviour; Creep*

1. Introduction

Structural Insulated Panels (SIPs) are high performance load-supporting panels, which are considered to be the next generation of timber construction in the UK. A typical make-up of SIPs comprises insulation core materials adhesively bonded to outer skins such as oriented strand board (OSB). As a novel structural material, they offer key advantages including satisfactory structural strength, super thermal performance, high strength-to-weight ratio and low environmental impact. The knowledge of SIPs as a load-supporting construction material is still very limited. This is exacerbated by the fact that the structural performance of SIPs has been reported to vary from manufacturer to manufacturer as they use different SIP construction and connection details.

SIP connections encompass panel-to-panel joints and connections between different structure members, such as wall-to-floor connections. There are a number of different panel-to-panel joint designs from various manufacturers. However, no universal standards or codes of practice are currently available for designing and detailing SIP connections.

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Most existing designs recommended by manufacturers need to be tested and approved by independent approval bodies.

Literature survey reveals three typical panel-to-panel joints, including OSB thin spline, foam block spline (or referred to as mini-SIP spline) and dimensional lumber spline.

Figures 1 illustrates the typical panel-to-panel joints.

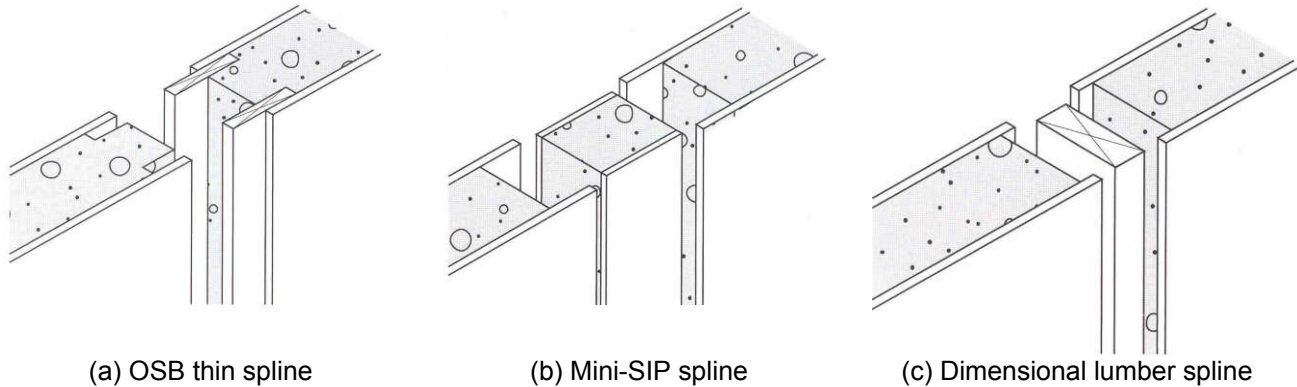


Figure 1: Typical panel-to-panel joints (Morley, 2000)

This paper will report studies conducted at University of Birmingham on structural behaviour of SIPs under both short-term and long-term loadings. The main objective of this study is to investigate structural behaviour (e.g. stiffness, loading capacity and creep) of SIPs with various panel-to-panel joints. A series of purposely selected SIP samples have been subjected to both short-term and long-term transverse loading test. Testing results have provided the first-hand data, which are not readily available in open literature. In this study, special focus has been placed on the effect of panel-to-panel joint on structural behaviour of SIPs under both short-term and long-term loading conditions. Displacements at various locations have been recorded throughout the entire loading regime. Failure loads and the corresponding failure modes have been identified. The obtained testing results can be used to validate the subsequent numerical modelling results.

2. Short-term experimental investigation on SIPs with various panel-to-panel joints

Short-term four-point bending tests of a series of SIP samples were undertaken at University of Birmingham. In this test program, joints with mini-SIP connections and dimensional lumber spline connections have been studied. The first type of joint in Figure 1 with OSB thin spline was not included due to the difficulty of fabrication in engineering practice. Since neither British nor European standards has specified standard testing method for SIPs, the four-point bending test for double skin metal faced insulating panels specified in BS EN 14509 was found suitable and hence employed. Figure 2 illustrates the four-point bending test details.

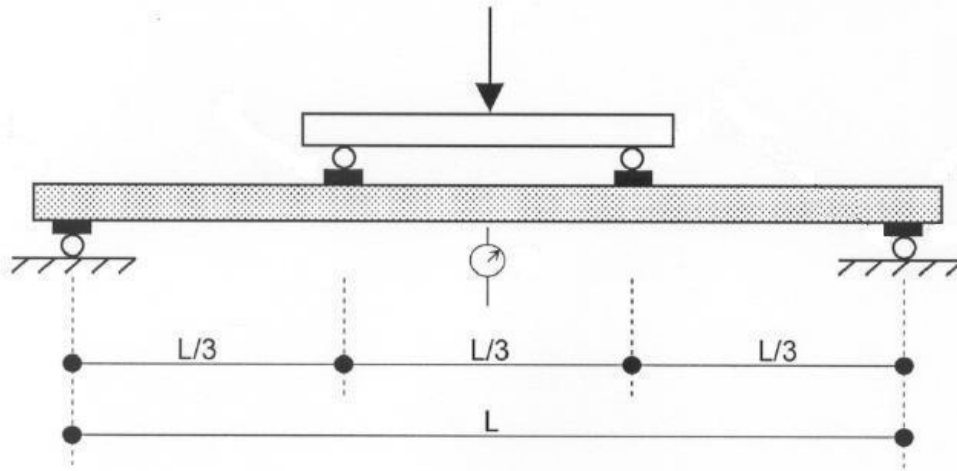


Figure 2: Four-point bending test (BS EN 14509, 2006)

2.1 SIP testing samples

Six SIP samples of three groups, i.e. two typical panels without any connections (TP1-1 and 2), two panels with the mini-SIP spline connection (TP2-1 and 2) and two panels with the dimensional lumber spline connection (TP3-1 and 2), were subjected to the four-point bending test until failure. The expected failure modes in this test include the inner core shear, debonding and outer face fracture/crushing. All test samples have half of the standard product size, i.e. 600 mm x 1200 mm. The principle of selecting sample size is that by testing most economic panel size, tests should be able to supply adequate results to fulfil the designated purpose. For instance, conclusions on the impact of joints drawn through these half-size samples can be rationally extended to full-size panels. It is obvious that results obtained from these tests may adequately serve as the benchmark example of the subsequent numerical modelling.

All panel samples were manufactured by SIP Build Ltd. The technique used to bond the inner core and outer faces is by injecting the PUR foam into the spacing between the two OSB skins and then curing to produce a strong bond.

TP1 has a 600 mm width and 1200 mm length with 11 mm thick OSB/3 facings and a 103 mm thick polyurethane inner core (overall thickness of 125 mm). Both short edges of the panel are inserted with C16 50x103 mm timber sections fastened by 2.8 mm diameter and 63 mm long nails with 150mm spacing, and also glued to the OSB faces and PUR core. Both long edges of the specimens are not inserted with any timber sections and are left with 50x103 mm rebates. Figure 3 shows the sample details of the first group of panel.

TP2 panel consists of two small panels, each being 300 mm wide by 1200 mm long with 11 mm thick OSB/3 facings and a 103 mm thick polyurethane inner core (overall thickness of 125 mm). The two small panels are joined along the centre-line by a mini-SIP spline fastened by 2.8 mm diameter and 63 mm long nails with 150mm spacing. Like TP1, both short edges are inserted with 50x103 mm timber sections. Both long sides of the sample are left with 50x103 mm rebates as previously described. Figure 4 shows the specimen details of the second group of panel.

Like TP2, TP3 consists of two identical small panels but is jointed by C16 dimensional lumber spline fastened by 2.8 mm diameter 63 mm long nails with 150mm spacing. The edge configurations are the same as TP1 and TP2. Figure 5 shows the specimen details of the third group of panel.

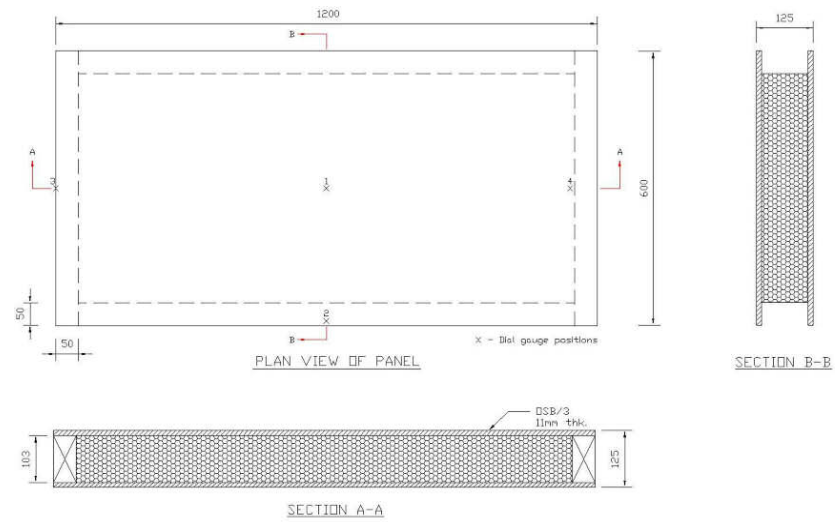


Figure 3: TP1 sample details

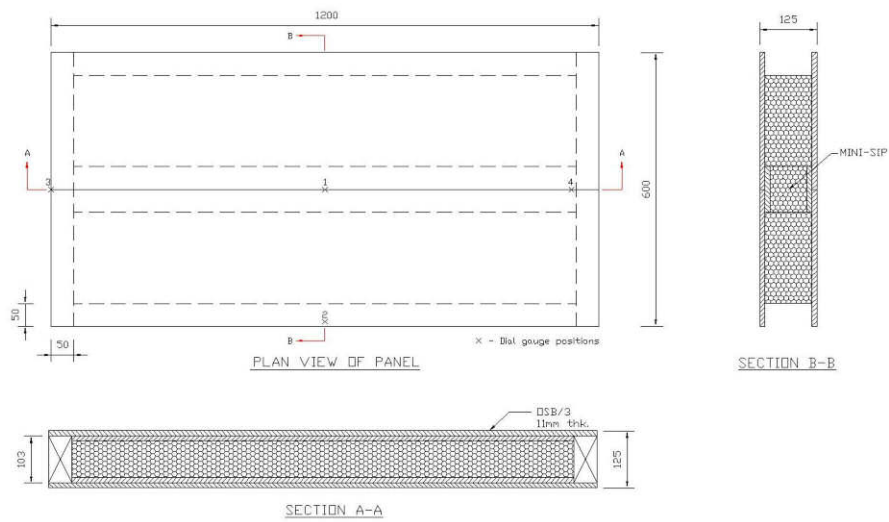


Figure 4: TP2 sample details

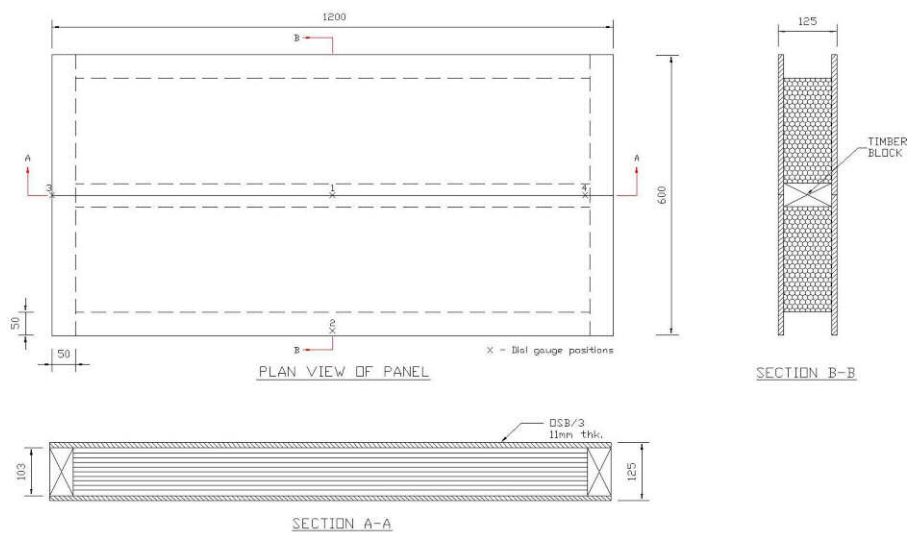


Figure 5: TP3 sample details

2.2 Experimental apparatus

Test panels were supported on two movable steel rollers which are placed on two steel I-beams. Between the roller and the panel, a 100 mm wide steel plate was placed to spread the reaction (see Fig. 6). Two line loads, which are 366 mm apart, were symmetrically applied through load spreading steel plates of size 600x100x10 mm and a steel roller of 30 mm diameter. The loads were then applied at suitable increments and the centre displacements were recorded until failure by using Mand Testing Machine. Figure 6 shows the layout of experimental apparatus for this test.



Figure 6: Experimental apparatus

2.3 Short-term test results

Table 1 shows the summary of the testing. It should be noted that the deflection of the panel becomes the governing factor of the loading capacity.

Table 1: Experimental findings summary

<i>Specimen</i>	<i>Load at Failure (kN)</i>	<i>Displacement at Failure (mm)</i>	<i>Load at deflection limit $L/333$ (kN)</i>	<i>Serviceability Load / Load at Failure (%)</i>	<i>Failure Mode</i>	<i>Increase of design loading capacity (%)</i>
TP1-1	19.32	34.84	2.87	15	Shear	0
TP1-2	19.32	42.90			De-Bonding	
TP2-1	20.32	42.35	3.06	15	De-Bonding	7
TP2-2	19.32	39.65			De-Bonding	
TP3-1	44.32	23.05	7.98	20	Flexural-Shear	178
TP3-2	36.32	21.54			Flexural-Shear	

Figure 7 shows the applied loads against vertical centre displacements of all three groups of panel.

As can be seen from Table 1 and Figure 7, TP3 panels (jointed by dimensional lumber spline connections) are the stiffest, which offers highest load capacity; whereas TP2

panels (jointed by mini-SIP connections) exhibit almost identical stiffness and failure loads to TP1. The loading capacity of TP3 governed by the deflection limit is 178% higher those of TP1 and TP2.

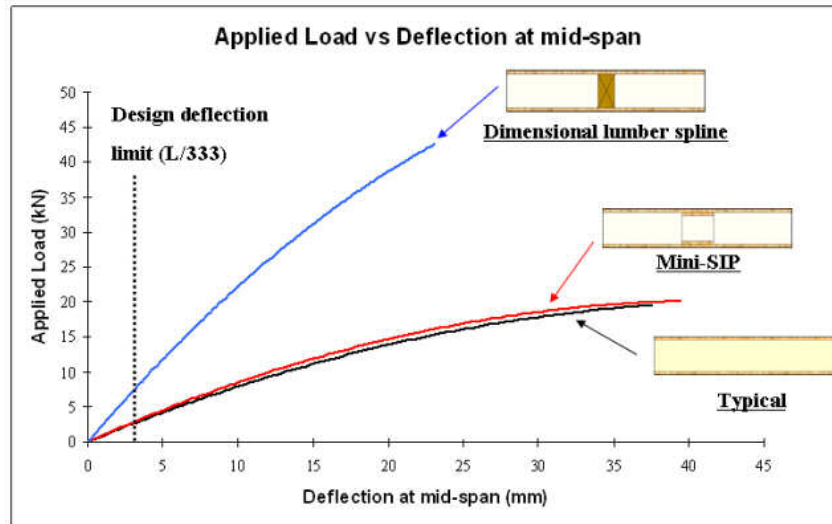


Figure 7: Load vs centre vertical displacement

This observation reveals that the mini-SIP joint has negligible impact on structural behaviours of SIPs whereas the lumber spline joint has significant impact. To increase the structural efficiency, the lumber spline joint is preferred. The quantitative increase of loading capacity, which may be affected by the dimension, the space of the lumber and the connection between the lumber and SIPs, e.g. the size and space of nails, is to be investigated.

3. Long-term experimental investigations on SIPs with various panel-to-panel joints

3.1 SIP samples and experimental apparatus

All three panels (TP1, TP2 and TP3), as previously described in Section 2.1, were subjected to the four-point bending creep test for three months under ambient temperature and moisture content. The magnitudes of the applied loads (shown in Table 2) are the serviceability loads (at the deflection limits in accordance with BS 5268-2, 2002, i.e. $L/333$) which were found from the short-term test and retained as a constant through the entire testing duration. The loads were applied to the panels through loading jacks supported by fixed steel box beams. Steel box beams were hold down onto the strong floor via threaded steel rods. The magnitudes of the applied loads were monitored by load cells. Figure 8 shows the layout of experimental apparatus for this test.

The creep deflections of each SIP samples together with temperature and relative humidity were then recorded at the following time points after initial loading: 0.1h, 0.2h, 0.5h, 1h, 2h, 4h, 8h, 24h and then every 24h. At each time of monitoring, the load was increased to its initial level and the set of deflection reading was also recorded.

3.2 Long-term experimental test results

The initial creep deflection of all panels is in the range of 3.9 - 4.1 mm, TP3 is found to have the lowest creep deflections at the same time. Figure 9 shows the comparison of the creep test results among all test panels.

Table 2: The applied loads and the initial deflection of each SIP specimen

<i>Specimen</i>	<i>Applied Load (SLS)</i>	<i>Weight of supporting elements</i>	<i>Total load</i>	<i>Applied Load / Short-term Load Capacity</i>	<i>Initial Deflection</i>
	(kN)	(kN)	(kN)	(%)	mm
TP1	2.9	0.25	3.15	15.8	4.1
TP2	3.1	0.33	3.43	17.3	3.9
TP3	8.0	0.29	8.29	20.6	4.0



Figure 8: Experimental apparatus

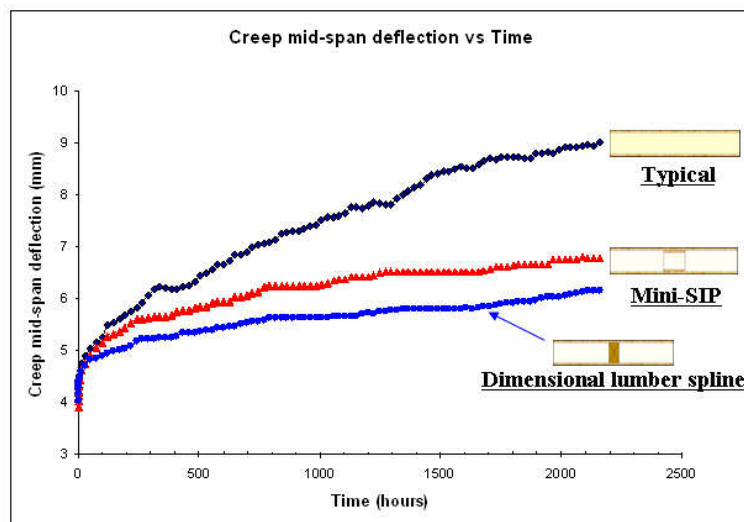


Figure 9: Three month creep test results

Test results show that the five element creep compliance model, provided by Taylor (1997) in Equation 1, is adequate to describe the three month creep test result. Moreover, creep parameters can be used to predict the creep behaviour at longer durations. Figure 10 illustrates five element creep compliance model prediction with three month creep test results.

$$\Delta(t) = \Delta_0 + A_1[1 - \exp(-A_2t)] + A_3t^{A_4} \quad (1)$$

where $\Delta(t)$ is total time dependent deflection (mm);
 Δ_0 is initial deflection (mm);
 A_i is creep parameters associated with creep deflection equations; and
 t is duration (hour)

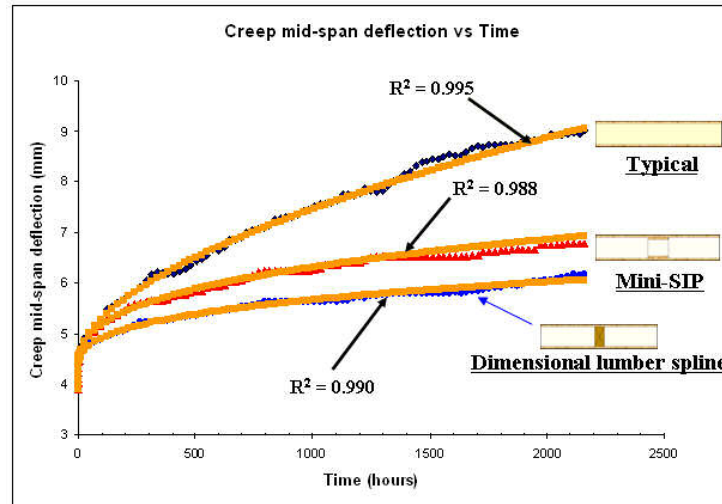


Figure 10: Five element creep compliance model prediction

4 Conclusions

The popularity of SIPs is increasing because of their favourable features. The short-term transverse loading test was carried out and test results show that the panels with dimensional lumber spline connections are the stiffest and therefore provide highest design loading capacity. Loading capacities of panels with mini-sip connections are found to be similar to the typical panels without any connections. Consequently, this indicates that the loading capacity is not subjected to any deduction when the mini-SIP connection is used. It has been also found that the serviceability ultimate limit load usually governs the design.

The long-term transverse creep test was also carried out and it has been found that the panel with dimensional lumber spline connection has the lowest creep deflections within the same duration. Furthermore, the five element creep compliance model has been found to be able to adequately describe creep test results and can be used to predict the creep behaviour in longer durations.

5 References

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